HURRICANE SEASON OF 1956

GORDON E. DUNN, WALTER R. DAVIS, AND PAUL L. MOORE

Weather Bureau Office, Miami, Fla.

1. GENERAL SUMMARY

The 1956 hurricane season was comparatively mild from the standpoint of storm frequency. Only eight tropical storms developed compared to an average during the past two decades of ten; four reached hurricane intensity compared to a normal of five during recent years. In only two of the past 15 years have tropical storms been so few and, by 1925 standards of detection and classification, possibly only three storms would have been designated as tropical. Two storms reached the coastline of the United States, both in the Gulf of Mexico.

The 1956 season was also mild from the standpoint of tropical storm intensity. One of the storms was of hurricane intensity for only a few hours, Flossy was of full hurricane intensity no more than 24 hours, and hurricane Greta was as much extratropical as tropical during her lifetime. Indeed only Betsy appeared to have all the characteristics of the classical hurricane and even this storm did not increase in intensity and size in accordance with statistical expectancy. None of the four hurricanes of 1956 could be classified as severe (120 to 150 knots sustained wind).

Tracks of the tropical storms of 1956 are shown in figure 1 and death and damage data are tabulated in table 1.

TABLE 1.—*Damage and deaths from all tropical storms and disturbances of 1956*

Type of storm	Date	Damage	Deaths*	Area
Tropical storm	June 13	$50,000	4	La., Miss.
Hurricane Anna	July 26	50,000	0	Tampico, Mex.
Hurricane Betsy	Aug. 11	10,000,000	18	French West Indies.
	" 12	25,500,000	9	Puerto Rico.
	" 13	380,000	0	Bahamas.
Tropical storm Dora	Sept. 12	Minor	27	Mexico.
Hurricane Flossy	" 24-25	24,774,000	15	Mostly in La., Miss., Ala., Fla.
Hurricane Greta	Nov. 1-4	1,680,605	0	Mostly Fla. east coast.
	" 3-5	1,899,201	1	Puerto Rico and other islands in Antilles.
Tropical disturbance	July 4-5	503,000	0	Alabama.
Quasi-tropical storm	Oct. 15-16	3,000,000	2	Florida.
Total in United States.		$30,007,605	19	
Total Atlantic hurricane area.		$67,836,806	76	

*Zero indicates no deaths reported.

2. INDIVIDUAL STORMS

Unnamed Tropical Storm, June 11–14.—This was the second tropical storm to occur in June in 10 years. On June 9, a fracture occurred in the polar trough lying just off the Atlantic coast, and the southern section began moving westward across Florida into the Gulf of Mexico while the northern section continued eastward over the western Atlantic. The westward moving southern section apparently induced an easterly wave which moved across the extreme western Caribbean, western Cuba, southern Florida, and the Yucatan Peninsula, and on the 12th formed a depression in the Bay of Campeche under the mid-tropospheric trough. The disturbance moved northward, acquiring tropical storm intensity and the center crossed the Louisiana coast a short distance west of Grand Isle during the late forenoon of the 13th. According to the report from the hurricane forecast center at New Orleans, "The storm had both tropical and extratropical characteristics. Rainfall was tropical in nature but never formed in bands characteristic of tropical storms and there was never any definite center or eye. The temperature aloft over the surface Low remained as cold or colder than the surrounding air." The situation in the high troposphere was also markedly different from that usually observed during hurricane formation. At 250 mb., at 0300 GMT on the 12th, an intense cyclonic circulation was centered southeast of Fort Worth and at 0300 GMT on the 14th this center had moved almost over the tropical storm in Louisiana.

The highest wind reported ashore was 55 m. p. h. from the east at Grand Isle, at 0715 CST on the 13th. A boat 5 miles south of Pilottown, La., reported gusts to 60 m. p. h. from the south-southeast. The lowest observed pressure was 29.66 inches at Moissant Airport, New Orleans, and at McComb, Miss. The highest measured tide was 4.7 feet above mean sea level at Biloxi, Miss.

The heaviest rainfall was within 100 miles of and to the east of the storm track and decreased from 6.13 inches at Grand Isle, La., to 5.60 inches at Monticello, Miss., 3.17 inches at Jackson, Miss., and 1.60 inches at Greenwood, Miss. The benefit to crops from these rains, which ended a drought at least temporarily, exceeded property losses from wind and water on the coast.

Four persons were drowned, three of them when a tug sank off the Mississippi coast and the other, a truck driver, when his truck skidded on the bridge over Lake Pontchartrain and plunged into the lake. The bridge was damaged by the truck but more seriously by a loose barge. The total damage to the bridge was estimated at $12,000.

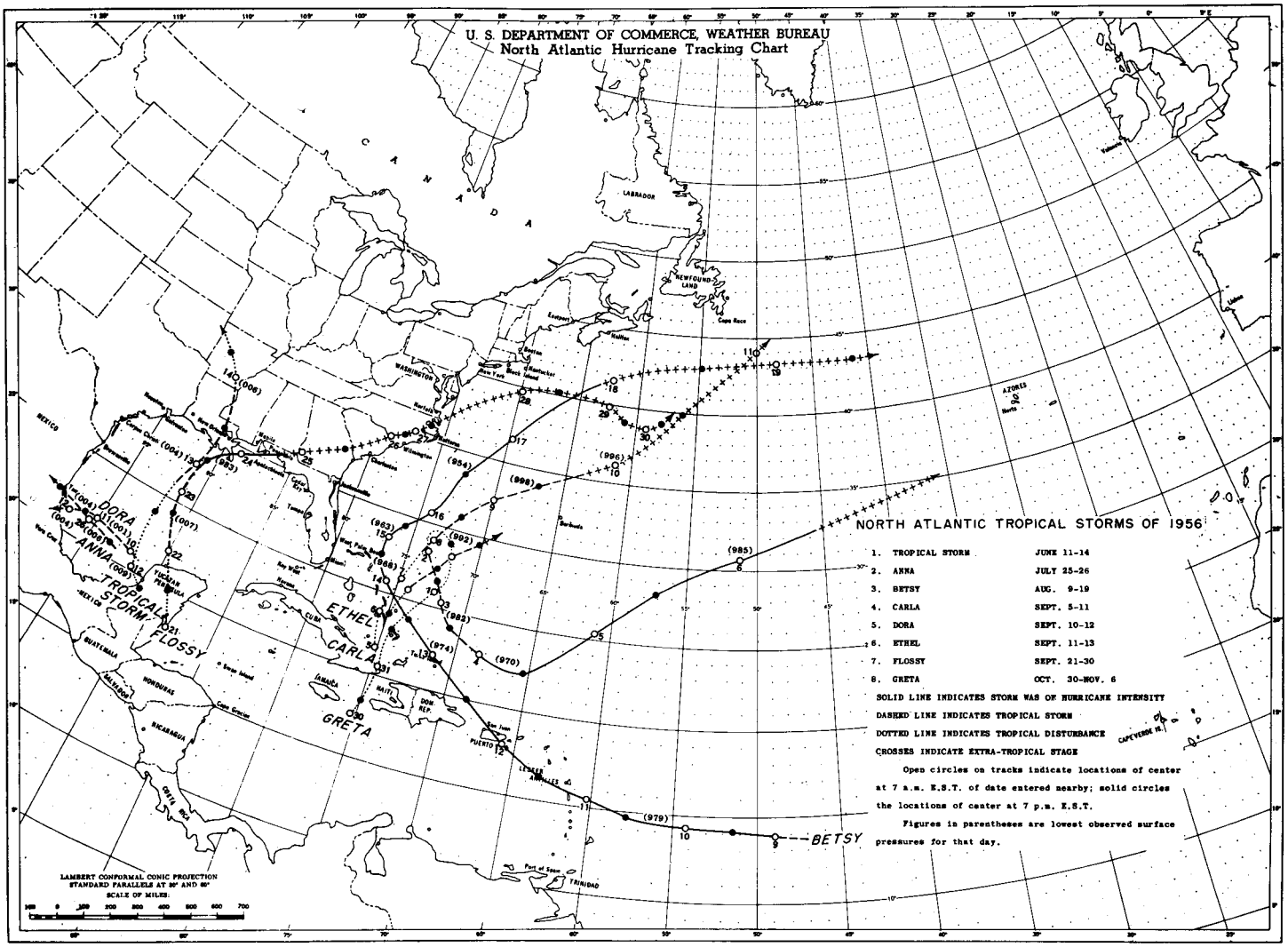

FIGURE 1.—Tracks of hurricanes and tropical storms that occurred during 1956 in the North Atlantic Ocean.

Tides generally ranged from 1 to 4 feet above normal along the Louisiana and Mississippi coasts. The Freeport Sulphur Co. suffered some damage to their sulphur mines near the coast south of Houma, La., where the tide was 4.5 feet above mean sea level. Minor damage to the beaches, small boats, and piers occurred along the Mississippi coast in places where tides were said to have reached as much as 5 feet above mean sea level. The total damage from this storm is estimated at $50,000.

Hurricane Anna, July 25–26.—The easterly wave in which Anna developed passed through the Lesser Antilles on July 20 and continued westward through the Caribbean. Instability of the wave began to increase on the 23d as the wave, extending on the surface from central Cuba to Panama, passed under a very well developed anticyclone in the middle and upper troposphere. A weak circulation may have developed as it moved over the Yucatan Peninsula on the night of the 24th but all surface winds were under 20 m. p. h. Intensification was steady after the center passed into the Bay of Campeche and the depression intensified to storm intensity on the afternoon of the 25th.

On the morning of the 26th, Navy reconnaissance located the center with lowest pressure 991 mb. (29.26 in.) and found maximum winds of 50 knots in the northern semicircle. Early that evening the center moved inland south of Tampico, Mexico where a maximum wind of 70 knots (81 m. p. h.) was reported with lowest pressure 29.60 inches. It is thought that winds of hurricane force existed only for about three hours as the center approached and crossed the coastline.

Many houses in the poorer sections of Tampico were blown down and some roofs of the better homes were blown off. Although only 2.5 inches of rain were reported, downtown streets in Tampico were flooded. There were no reports of deaths or injuries. Damage has been estimated at around $50,000.

Hurricane Betsy, August 9–19.—The general circulation over the Atlantic during most of the hurricane season of 1956 and its possible relationship to the mild hurricane

activity will be discussed later. A temporary break in the prevailing circulation pattern occurred early in August as the Azores-Bermuda anticyclone moved northeastward for a period of about a week and intensified while a trough extended through western Europe. Similar patterns have been noted previously [1] as antecedent to hurricane formation. Apparently the injection of cold air aloft and cyclonic vorticity into the Tropics by a meridionally-extensive trough encourages the transformation of stable waves in the easterlies, and even in the intertropical convergence zone, into unstable waves and eventually into storm circulations. Around August 9, when the development of Betsy was first suspected, the anticyclone had reached maximum intensity and immediately began to subside and to return to its previous position south of its normal location.

Lack of reports in the eastern Atlantic makes it impossible to arrive at a detailed analysis for the period preceding the first indications of this storm but there was some evidence of an easterly wave near longitude 33° W. on August 6. Extrapolation at a normal rate of movement would have brought it to the vicinity of 50° W. on the 9th. On that date the following report was received from the *M/T Marisa:* "At 1218 GMT passed through trough of tropical storm in position 14.05° N., 55.25° W. At 1200 GMT 1008 mb., winds force 10, very high wild sea, heavy squalls." It was not possible to fit this report into any logical analysis and consequently efforts were made to verify the ship's position. At 1730 GMT a corrected position of 14.05° N., 49.05° W. was obtained. This was only a short distance from the routine Gull Papa reconnaissance track but the developing storm was too small to alert the reconnaissance observer and there was no diversion from the scheduled track.

A special reconnaisance flight was made on August 10, but confirmation of storm development was received through surface ship reports before the plane reached the area. The *M/S Sagoland* at 1200 GMT reported: "Lat. 14.35° N., Long. 54.10° W., at 0400 GMT, wind 035 degrees increasing force 5, barometer 1008 mb. At 0930 GMT northeast force 11/12, barometer 1004, violent sea, heavy rain, no visibility. At 1200 GMT wind east force 6, barometer 1009, heavy seas, rain, decreasing sea." The 1200 GMT observations from the *SS Mormac Lark* and *SS Willemstadt* on the outskirts of the storm, were also helpful in the location of the storm and evaluation of its intensity.

The first advisory was issued at 1100 EST, August 10, at which time a hurricane watch was advised for the Leeward and Windward Islands from Antigua to Barbados. When reconnaissance aircraft reached the storm later in the day, it was found to be a very small hurricane but with winds of 120 m. p. h. near the center and central pressure 979 mb. The eye was defined by a very tightly closed pattern on the radar as only 10 miles in diameter.

The hurricane moved on a west-northwest course at about 17 m. p. h. during the next 24 hours and passed through the central Lesser Antilles about midday August 11. It crossed over the island of Marie Galante and between Isle des Saintes and the extreme south portion of Basse Terre, Guadeloupe. Reports indicate 18 lives lost and severe damage. On Guadeloupe, 1,000 dwellings were extensively damaged, all communications disrupted, and 50 to 60 percent of the banana, breadfruit, coconut, and papaya trees destroyed, a serious blow to the economy of the island. The banana crop loss was estimated at $3.5 million and preliminary estimates give $10 million for the total damage figure. Winds were estimated at 100 to 120 m. p. h. on Guadeloupe and the lowest pressure was 991 mb.

After moving through the Leeward Islands, the hurricane began a more northwesterly course, passing about 30 miles south of St. Croix, Virgin Islands, and reaching the southeastern tip of Puerto Rico in the early morning of August 12. Prior to reaching Puerto Rico the storm displayed a small but apparently real oscillatory motion about the mean track with an amplitude of a little less than ½ degree and a period on the order of one day. The oscillation was sufficiently definite that some forecast use could be made of it, on an extrapolation basis. Following the turn to a more northwesterly direction, this oscillation was not present or was obscured.

A hurricane watch had been ordered for Puerto Rico and the Virgin Islands on the evening of August 10. As the hurricane continued to move toward Puerto Rico, the watch was changed to hurricane warnings on the afternoon of August 11. The eye of the storm crossed Puerto Rico between 1200 and 1530 GMT, August 12, on an erratic coarse [2] between northwest and west-northwest at about 17 m. p. h., emerging on the north coast near Camuy with only slight and temporary weakening of its circulation. According to reports, all of Puerto Rico, except the southwestern portion which was protected by the mountain backbone of the island, experienced winds of 75 m. p. h. or higher in gusts. Maximum sustained winds at San Juan were 73 m. p. h., with gusts to 92 m. p. h. Rainfall totalled 3.19 inches. Ramey Air Force Base, on the northeastern tip of the island, recorded wind gusts to 115 m. p. h. Nine deaths were reported in Puerto Rico and the property damage totalled $25,500,000 or more.

Hurricane Betsy continued at a speed of about 17 m. p. h. to near Turks Island early on August 13 and, with some acceleration, reached the vicinity of San Salvador in the Bahamas about 2000 EST on that date. Winds at San Salvador reached 132 m. p. h. in gusts. Sustained winds were 100 m. p. h. or more. Approximately 5 inches of rain fell in 5 hours. Several houses were demolished and most of the churches, which are generally better constructed, lost their roofs.

Aircraft reconnaissance on August 13 had shown a slight increase in size of the storm but little change in central pressure or maximum winds. Gale winds were reported as extending 125 miles north and 60 miles south of the center. Lack of important increase in size or

intensity was compatible with the fact that turbulence and rain in all quadrants were predominantly light with only intermittent bursts of heavy rain and moderate turbulence. On the 14th, central pressure was reported as 960 mb., the eye was 12 miles in diameter and well formed, and associated clouds extended 250 miles north and 200 miles to the east.

On August 14 and 15, Betsy began recurvature with sharp deceleration in forward movement. By the 16th it was moving toward the northeast and had increased its forward speed to about 20 m. p. h. Between the 13th, when the storm was near Turks Island, and the 16th, when a dropsonde was released in the eye near 30° N., 75° W., temperatures in the eye between the surface and 700 mb. fell about 2° C. The normal sea-surface temperature difference between these areas is less than 1° and, while some anomaly may have existed, it seems likely that the cooling was an indication of the beginning, even at this time, of some other factors interfering with the efficiency of the storm engine. By the 17th, a dropsonde in the eye showed that the cooling, by another 1° to 3° C., extended upward to almost the 500-mb. level. Maximum winds began to decrease on the 16th and by late August 17th had dropped to 80 m. p. h. Reconnaissance at this time reported the eye was becoming poorly defined as the hurricane moved northeastward at about 23 m. p. h. past the latitude of Nantucket. The last advisory was issued on the morning of August 18 as the storm assumed more extratropical characteristics. It moved due east on the 19th and 20th, gradually losing its identity.

The tracking and forecasting of hurricane Betsy was aided by the availability of more information in the form of air-borne and land-based radar observations and upper air soundings than in previous years. The storm successively came within range of radar at San Juan [2], the Air Force missile range stations in the Bahamas, and the Navy Hurricane Central at Miami. The AN/CPS–9 radar at the Navy Hurricane Central, Miami, established what possibly may be a record when hurricane Betsy was off the Florida coast on the 14th. The center of Betsy was initially detected by this radar at a range of 293 nautical miles and presented a perfect scope picture for the next 26 hours until she was lost at 269 nautical miles.

Aircraft reconnaissance by the Air Force and Navy was up to its usual high standards. Despite all this, Betsy was not without forecasting problems. The most difficult problem, as it usually is, was the recurvature. From the time of inception until August 13, the movement was consistent and could be forecast with a high degree of confidence. However, on that date the center was approaching an area where recurvature appeared to be a likely possibility on the basis of climatology, and a slight possibility on the basis of the prevailing circulation. From the standpoint of public warnings, the problem was further complicated by the relatively rapid movement of 18 m. p. h. (during certain short periods on this date it appeared to move as fast as 25 m. p. h.) and the time-of-day factor. At 1700 EST, on the 13th, it was decided that with the rate of advance and the direction and speed of movement indicated by the Riehl-Haggard [3] technique, which gave excellent results on the whole with this storm, squalliness could develop on the Florida southeast coast on the forenoon of August 14. If hurricane warnings were delayed until the next morning, and the forecast track verified, insufficient time would remain for adequate preparations. Consequently, hurricane warnings were issued for a portion of the Florida east coast. The underlying reasons for the action, and the degree of uncertainty attached to a hurricane forecast for such a period of time, were expressed in the public advisory. By the morning of August 14 stronger evidence in favor of a northward turn was appearing, and later in the day all hurricane warnings were lowered. However, there remained another 24 hours of slow movement during the recurvature process before all threat to the United States coast had definitely passed.

At 500 mb., during the early history of Betsy, a trough extended from Newfoundland to near Bermuda. The southern portion of this trough tended to fill as Betsy moved past, and heights in the area of an anticyclone along the southeastern United States coast had been rising for some time when the storm reached the area of Turks Island on August 13. This, with other factors, created some doubt as to whether recurvature could occur east of Florida. The long-wave pattern at this time was becoming poorly defined and of small amplitude, with indications that a trough should develop in the Great Lakes region, permitting the High along the southeastern coast to persist and hamper recurvature. It was not until the 14th that developments, including the weakening of the High over the southeastern coast, began to favor the northward turn.

The accepted movement-forecast techniques were applied and were found useful to varying degrees. None were without failures at some stage, particularly during recurvature. Three 24-hour forecasts obtained by the Riehl-Haggard technique were within 17 miles, which is as close as the center can usually be located at sea. However, passage of the storm through the network of upper-air stations at Air Force missile bases and on islands to the south permitted the collection of data which may prove helpful in analyzing some of these deficiencies in our present knowledge of hurricane behavior. This is especially true of the upper troposphere, for which we have previously had severely limited data.

There were at least 27 deaths connected with Betsy, and total damage in monetary terms, including an estimate of $380,000 in the Bahamas and a few other islands, appears to be around $35,880,000.

Tropical Storm Carla, September 5–11.—The first indication of Carla appeared on September 5 when a weak circulation showed up in an easterly wave which was moving into the southeastern Bahamas. During the next several days it moved on a parabolic course and on the

7th recurved northeastward with some deepening and the area of strong winds expanded to cover an area 300 to 400 miles in diameter.

A strong southeastward outbreak of polar air was taking place in the eastern and central United States and the accompanying cold front passed off the east coast during the morning of the 7th. On the 8th interaction between the High with central pressure 1034 mb. over the Lakes Region and the tropical Low off the southeastern United States coast was causing strong northeast winds from the central Florida coast northeastward along and off the Georgia and Carolina coasts. Gales spread to the New England coast as the Low moved to a position near Lat. 32.5° N., Long. 70° W. by the morning of the 9th. Reconnaissance aircraft on the morning of the 9th located an ill-defined center but reported no eye existed and no spiral bands were in evidence. Highest surface winds near the center were estimated at 30 knots. However, 40 to 50 m. p. h. winds were found extending 200 miles to the west and northwest and 40 m. p. h. winds some distance to the east and south. During the period of greatest intensity, the storm was probably not a true tropical storm. It had definitely taken on extratropical characteristics by the forenoon of the 10th and only three advisories were issued.

On the morning of September 5, when the weak easterly wave extended northeast-southwest through the southwestern Bahamas, a weak trough or shearline existed in this area at all levels to 500 mb., with a deep Low at 300 mb., about 700 miles to the northeast near Lat. 26.5° N., Long. 62.5° W. During the next two days this 200-mb. Low seemed to split, with one section moving off to the northeast and the other drifting southwestward over Cuba into the northwestern Caribbean and over the Yucatan Peninsula by the evening of the 8th. At about this same time, the polar trough at the mid-troposphere was moving off the coast of the southeastern States and deepening, and by the morning of the 10th, Carla, now almost entirely surrounded by cool air at lower levels, was pulled into the trough and carried rapidly out over the Atlantic to the northeast.

Thus it may be seen that during the formative stage of Carla, it was never in a favorable location with respect to the 200-mb. high pressure cell to augment deepening.

Tropical Storm Dora, September 10–12.—A tropical storm formed during the afternoon of September 11 in the southwestern Gulf of Mexico in a depression that had been drifting westward. Navy reconnaissance during the previous afternoon found a rather large area in the Bay of Campeche with scattered squalls. The lowest pressure was 1010 mb. and the maximum wind 35 knots.

On the 11th, aircraft reconnaissance found the lowest pressure to be 1004 mb. and the maximum wind 65 knots. This storm has not been classified as a hurricane since the 65-knot wind was an estimate and not a measurement, and it is not believed that the required pressure gradient for this speed existed. The next morning the minimum pressure was the same and maximum winds were 50 knots. The center moved inland around noon near Tuxpan, Mexico with lowest pressure 1002 mb. and highest wind 30 knots.

The New Orleans forecast center reported that heavy rains in Mexico caused a landslide in which 13 persons in a bus were killed and these deaths were attributed to the storm. Some flooding occurred from the heavy rains, but damage is believed to have been slight. A later news dispatch said, "The death toll from after-effects of Mexico's short lived Hurricane Dora rose to 27 today with reports of 7 persons drowned in the overflowing Pachuapan River near San Andrés Tuxtla."

At 200 mb. the storm remained south of, and about midway between, a High centered over Texas and a trough over the eastern Gulf—not a very favorable location for rapid intensification.

Tropical Storm Ethel, September 11–13.—At 1330 EST September 11, a weak circulation was noted over Great Exuma Island in the Bahamas, about 100 miles south of a quasi-stationary front. During the next 24 hours the tropical depression moved north-northeastward and gradually intensified. On the afternoon of the 12th, research aircraft reconnaissance entered the storm and found a well-developed eye about 20 miles in diameter and entirely surrounded by a typical wall cloud extending upward about 30,000 feet. A maximum wind of 66 knots was encountered while entering the eye over a distance of some 3 miles in the northeastern quadrant. Thirty-knot winds extended outward 30 to 100 miles in all directions but no hurricane winds were found in any other quadrant.

By late on the 13th, the storm had assumed extratropical characteristics and lost intensity. It is thought that the storm may have developed strongly for a short time as a new source of energy in the form of cold air entered the system. Since development took place under a broad polar trough, even this much intensification was surprising. If the research plane had not flown into the storm on the 12th, no advisories would have been issued and it would not have been listed as a tropical storm.

Hurricane Flossy, September 21–30.—The origin of this hurricane—the only one to reach the coast of the United States in 1956—is rather obscure. Hurricane squalls were reported in the Pacific south of Guatemala on the 20th, and the initial impulse may have moved northward from there or from the Caribbean. The first well-developed circulation was noted over the Yucatan Peninsula at 1330 EST on the 21st, passing into the Gulf of Mexico near Merida. According to the report of the hurricane forecast center at New Orleans, the circulation intensified gradually while moving northward over the Gulf and reached storm intensity on the afternoon of the 22d. After this time the size of the storm increased considerably but the pressure gradient around the center intensified only slowly. The tropical storm reached hurricane force near or somewhat before noon on the 23d

when the center was about 125 miles off the southeastern Louisiana coast.

During the afternoon the hurricane turned rather sharply toward the east-northeast, crossing the Mississippi delta a little north of Burrwood near Pilottown early on the 24th. Here it seems to have reached maximum intensity with highest wind at Burrwood 84 m. p. h. and lowest pressure 29.03 inches. An oil rig a little west of Grande Isle reported a maximum wind of 83 m. p. h. and gusts to 95. The New Orleans forecast center attributes the turn to the east-northeast to "the central core of the hurricane building upward and reaching into the westerlies." This change in direction was also indicated by the Riehl-Haggard forecasting technique. The center passed a little south of Pensacola, Fla., during the afternoon and later about over Fort Walton. The storm became extratropical shortly after the center passed out of Florida but it moved northeastward inside the coastline as an energetic storm until it passed out to sea near the Virginia Capes.

As far as known, no hurricane winds were reported at any Florida point although winds were near hurricane force eastward along the coast to Panama City. The lowest pressure reported during the storm was 28.93 inches at the Pensacola Naval Air Station. The highest storm tide was 7.4 feet m. s. l. at Laguna Beach, Fla. Some higher values were reported along the eastern side of the Mississippi delta but have not been verified. Tides flooded portions of Norfolk, Va., and water stood 2.5 feet deep in several of the principal streets. Beach erosion occurred as far north as Delaware.

The heaviest rainfall reported was 16.70 inches at Golden Meadow, La., and 16.30 inches at Gulf Shores, Ala. The rainfall intensity decreased gradually as the storm moved northeastward but 1 to 3 inches fell as far north as Virginia. Three tornadoes were reported in advance of the storm in northwestern Florida and another at Hilton Head Island near Savannah, Ga., but each caused only minor damage.

Total damage in the States of Louisiana, Florida, Alabama, and Mississippi was $24,774,000 of which $15,204,000 was to crops. Damage in other States such as Georgia, the Carolinas, and Virginia was $100,000 or less and was greatly outweighed by the beneficial rains which relieved drought conditions. Deaths, mainly from plane and automobile accidents attributed to the storm, totalled 15. Warnings throughout the storm were timely and accurate.

The origin of Flossy has been discussed by Hawkins [4] and its transformation to an extratropical storm by Richter and DiLoreto [5].

Hurricane Greta, October 30–November 6.—A depression, which is believed to have had its origin along the intertropical convergence zone over the southern Caribbean, was first noted southeast of Jamaica on October 30 when a Navy reconnaissance flight observed 35-m. p. h. southeasterly winds. Numerous showers and a large area of relative calm near the location of lowest pressure were also observed.

The Woods Hole Oceanographic Institution research vessel *Crawford*, on a weather mission in the Caribbean, was very near the circulation center during the afternoon and evening of the 30th and encountered 25 m. p. h. southeasterly winds and a minimum pressure near 1005 mb. (29.68 in.). A radiosonde observation taken by the *Crawford* shortly after their winds shifted from the southeast to northwest indicated the Low was definitely cold-core as opposed to the warm core associated with hurricanes.

The Low continued northward at about 15 m. p. h. with a gradual intensification and by November 1 the lowest pressure had decreased to 998 mb. (29.47 in.). Winds of 30 to 40 m. p. h. were reported over a large area surrounding the center, but gentle variable winds and calms still covered an extensive area near the center.

A large high pressure system, which had stagnated some distance off the middle Atlantic coast during the last few days of October, blocked further northward movement so that during the night of November 1, the storm looped and took a southeastward course with a somewhat slower speed. It was during this period, as shown by data received from planes of the National Hurricane Research Project, that Greta assumed tropical storm characteristics with a minimum pressure of 992 mb. (29.29 in.).

It is believed that Greta reached hurricane intensity on the afternoon of November 3 or early on the 4th, and continued to intensify until November 5 when winds in excess of 100 m. p. h. and a minimum pressure of 970 mb. (28.64 in.) were reported by reconnaissance aircraft. During this period the forward motion became east-northeast at 20–25 m. p. h. On November 6 and 7 the storm continued east-northeastward at an accelerated speed, gradually assuming extratropical characteristics due to much colder ocean temperatures and an influx of cold air.

In many ways Greta was a most unusual tropical cyclone. For a long period it had all the characteristics of a cold Low from middle latitudes. There is some evidence that it may have been similar to the Kona storms of the Pacific both in origin and size. The rapid intensification to hurricane force with a southeastward movement has been rarely observed. Middle-latitude conditions at this time indicate an energy transfer from upstream may have occurred.

The circulation formed by the hurricane and the large anticyclone to the north covered a tremendous expanse of the Atlantic Ocean and the long fetch of the strong winds set up much larger waves and swells than indicated by the normal wind-sea-swell relationships. On the south Atlantic coast, damage was worst along the Jacksonville beaches where the water is relatively deep a short distance offshore. Damage in Puerto Rico from swells at least 20 feet high was heavy. Sta. Lucia, B. W. I., reported 20-foot swells from the west-northwest and some as much as

25 feet high. The French West Indies suffered severely with 80 percent of the port installations destroyed at Basse Terre, Guadeloupe. Damage, almost entirely from sea action, was as follows:

Jacksonville beaches, Florida	$1, 170, 605
Elsewhere along southeastern U. S. coast	510, 000
Puerto Rico	1, 194, 701
Virgin Islands	45, 000
Dominica	291, 500
Sta. Lucia and Pigeon Island	68, 000
French West Indies	200, 000
Other Caribbean Islands	100, 000
Total	$3, 579, 806

There was one death in Puerto Rico by drowning of the occupant of an exposed house who did not heed a warning to evacuate.

3. OTHER TROPICAL OR QUASI-TROPICAL DISTURBANCES

An unusual number of tropical disturbances which failed to acquire winds of as strong as 40 m. p. h. were noted this year. If entirely tropical in nature, most of them can be classified as tropical depressions which may be defined as weak cyclonic disturbances of tropical origin and with winds less than 40 m. p. h. Since some of these tropical and quasi-tropical disturbances were of some importance, a partial list follows:

Tropical depression, June 17–18.—A tropical depression, which briefly caused squalls up to 40 m. p. h., was located 500 miles east of the south Florida coast on June 17–18. Little evidence of it could be found after 1330 EST on the 18th. The lack of deep easterlies north of the area, and troughy conditions over the disturbance at 200 mb. were considered unfavorable for development.

Tropical depression, July 4–8.—A complete although very weak circulation was noted at 1930 EST on July 4, at Lat. 26.2° N., Long. 86.2° W., developing under a cold trough in the mid-troposphere. It moved north-northwestward and northwestward on the 6th causing gusts of 38 knots at Panama City and moved inland near Pensacola late on the 6th where the lowest barometer noted was 1011 mb. Whatley, Ala., reported 14.22 inches of rain during the storm and 10.85 inches in 24 hours.

Property damage was estimated at $400,000 from the heavy rains, plus $100,000 crop and $3,000 livestock damage. Many highway and railroad bridges were washed out and erosion of roads was extensive.

Tropical depression, August 28–September 6.—On August 28 an unusually strong wave on the intertropical convergence zone began approaching the Cape Verde Islands and soon developed considerable intensity. Station SAL in the Cape Verdes on the 31st observed a barometer reading of 1004 mb. Several ships in the area reported winds of 35 to 40 knots. After leaving the Cape Verde area, the storm apparently gradually decreased in intensity and finally dissipated northeast of the Leeward Islands on the 6th.

Tropical depression, September 13.—A vigorous depression passed through the Cape Verdes on the 13th, attended by squalls. Maximum winds are unknown. The depression was completely damped out before reaching the Antilles .

Tropical depression, October 9.—Some 1,300 miles east of Puerto Rico on this date, ships reported squalls of 40 to 45 m. p. h. and there was evidence of at least a quasi-circulation It was completely damped out within 24 hours.

Tropical depression, October 10–12.—Probably developing from the same easterly wave but farther to the north, a tropical depression formed on October 10 and moved in a general northerly direction for several days without further development. It was not the same depression noted on the 9th.

Quasi-tropical Low, October 13–19.—This Low formed as a wave on a dissipating polar front north of Hispaniola on the 12th and moved west-northwestward to the extreme southeastern Florida coast south of Miami on the 15th, when it turned north and north-northeastward passing over the North Carolina Capes west of Cape Hatteras. Rainfall was excessive in portions of Florida ranging from 6 to 20 inches over a 50-mile wide belt from the northeastern corner of Lake Okeechobee to Jacksonville. This storm never became wholly tropical, and maximum winds and most of the precipitation occurred well in advance of the low pressure center. Highest winds reported were gusts of 60 to 65 m. p. h. and probably some sustained winds of near 60 m. p. h. at sea. Damage from flooding in Florida, particularly around Kissimmee, totaled about $3,000,000. Two persons were drowned in the surf during the storm.

4. POSSIBLE CAUSES OF THE COMPARATIVELY MILD HURRICANE SEASON

One of the currently accepted requirements for hurricane formation is a warm sea surface with temperature 80° F. or higher. Riehl [6], however, has failed to find useful correlations between sea surface temperature anomalies and hurricane formation on a monthly or yearly basis. At the same time when the time scale of correlation was increased to 5 years and more, some improvement in the correlations was noted.

On the other hand, Fisher [7] has found some evidence, although not conclusive, that hurricanes tend to form near relatively warm ocean areas, that they tend to follow tracks along the areas of warmest water, and that they tend to weaken when they move over pronouncedly colder water. Some of the examples cited by Fisher appear to require a high degree of subjective interpretation.

At the time of preparation of this article, the sea surface temperature anomalies for this hurricane season have been analyzed for June, July, and August. During these months, sea surface temperatures appear to have been near or above normal everywhere in the western and central portions of the tropical Atlantic. Samplings for October indicate negative departures from normal [8]. Since sea

surface temperature anomalies are probably a result of abnormalities in the general circulation, it may be difficult to separate the effect of each in inhibiting or encouraging hurricane incidence.

Another generally accepted requirement for hurricane development is the existence of some preexisting disturbance. Easterly waves reaching the eastern Antilles appear to have been about normal in number but perhaps weaker than usual. The number of tropical depressions which failed to develop into tropical storms was greater than normal and this was particularly true in the western tropical Atlantic throughout the season and in the Cape Verde region in August and September.

Thus, largely by the process of elimination we are forced to turn to the general circulation in an effort to find the causes of the subnormal hurricane season. The requirements of an essentially barotropic atmosphere in the low and middle troposphere and a deep easterly current are provided by certain circulation types. In June the subtropical ridge was located considerably north of its normal position in the eastern United States and most of the Atlantic. Namias and Dunn [1] have indicated that this is favorable for tropical storm activity. To a lesser extent this same situation obtained in October and in both these months tropical storm activity was normal or above.

However, from early July into early September, the circulation over the Atlantic Ocean in 1956 differed radically from that of 1954 and 1955 and indeed many of the years since the early 1930's. In 1954 and 1955 the westerlies were far north of their normal position and during the greater part of 1956 were south of their average position. According to Jerome Namias,* fast westerlies (the speed of the westerlies is usually above normal when their principal axis is comparatively far south) inhibit the deployment into the Tropics of deep polar air masses which must be prolonged and persistent to provide a favorable upper-air climate for hurricane genesis. Unusually low-latitude westerlies in the Atlantic contract the area of deep easterlies. This same circulation type tends to shunt any hurricanes which do form away from the North Atlantic and Middle Atlantic coasts. At the same time, even though the overall hurricane frequency decreases, hurricane activity increases somewhat locally over the Gulf of Mexico, Florida, and the Caribbean.

During most of September, the position of the strongest westerlies was about normal and there were a considerable number of incipient tropical disturbances (depressions) which failed to intensify materially. In other words, there was some persistent inhibiting factor which has not yet been identified. It may have been subnormal sea temperatures in some areas, unfavorable upper-troposphere conditions, or some facet of the general circulation. Although Hawkins [4] found that circulation over the Atlantic in September resembled that of 1955 to a considerable extent and that strong and deep subtropical easterlies were prevalent, this never seemed to be the case in the area where the depressions formed. Almost invariably these disturbances formed under a relatively cold trough which we normally consider an unfavorable location for hurricane development.

Hawkins [8] has pointed out that the mean circulation pattern at 700 mb. during October 1956 was similar to patterns that Ballenzweig [9] found to be generally favorable to hurricane development and subsequent incidence in the Florida area. To account for the single quasi-tropical Low this October, Hawkins noted that a sampling of sea surface temperatures over the Gulf, Caribbean, and tropical Atlantic indicated below normal values for the month, but he made no attempt to relate this anomaly to the atmospheric circulation of preceding months.

*Personal communication to the authors.

REFERENCES

1. J. Namias and C. R. Dunn, "The Weather and Circulation of August 1955—Including the Climatological Background for Hurricanes Connie and Diane," *Monthly Weather Review*, vol. 83, No. 8, Aug. 1955, pp. 163–170.
2. R. J. Grace, "Betsy's Roving Eye," *Monthly Weather Review*, vol. 84, No. 8, Aug. 1956, pp. 311–312.
3. H. Riehl, W. H. Haggard, and R. W. Sanborn, "On the Prediction of 24-Hour Hurricane Motion," *Journal of Meteorology*, vol. 13, No. 5, Oct. 1956, pp. 415–420.
4. H. F. Hawkins, Jr., "The Weather and Circulation of September 1956—Including a Discussion of Hurricane Flossy and September's Typhoon Tracks," *Monthly Weather Review*, vol. 84, No. 9, Sept. 1956, pp. 336–342.
5. D. A. Richter and E. A. DiLoreto, "The Transformation of Hurricane Flossy into an Extratropical Cyclone, September 25–29, 1956," *Monthly Weather Review*, vol. 84, No. 9, Sept. 1956, pp. 343–352.
6. H. Riehl, "Sea Surface Temperature Anomalies and Hurricanes," *Bulletin of the American Meteorological Society*, vol. 37, No. 8, Oct. 1956, pp. 413–417.
7. E. L. Fisher, "Hurricanes and the Sea Surface Temperature Field," Department of Meteorology and Oceanography, New York University, *Technical Paper* No. 1 on contract with U. S. Weather Bureau National Hurricane Research Project, July 1956.
8. H. F. Hawkins, Jr., "The Weather and Circulation of October 1956—Including a Discussion of the Relationship of Mean 700-mb. Height Anomalies to Sea Level Flow," *Monthly Weather Review*, vol. 84, No. 10, Oct. 1956, pp. 363–370.
9. E. M. Ballenzweig, Seasonal Variations in the Frequency of North Atlantic Tropical Cyclones Related to the General Circulation, unpublished report of U. S. Weather Bureau, Extended Forecast Section, Sept. 1956.